

Spatio-temporal variation in rainfall-runoff erosivity over Akwa Ibom state using annual and monthly precipitation

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ABSTRACT

Soil erosion has been known to be a major environmental threat globally. In the tropics, rainfall is the initiator of soil erosion by water through the detachment and runoff processes. In modeling soil erosion by water, rainfall erosivity is considered as the driving energy force. Its study is important in understanding the rainfall erosivity index. The method proposed by Arnoldus, (1980) was used in this study based on the availability of the monthly and annual rainfall data. The study area was divided into upland and coastal region in order to understand the spatio-temporal variation in rainfall-runoff erosivity over Akwa Ibom state. A rainfall data of (1985-2018) 34 years was obtained from Nigerian Meteorological Agency (NIMET) and (2010-2018) 9 years rainfall data was obtained from the Akwa Ibom State Airport Meteorological station. The amount of rainfall for the upland ranges from 1840.7 to 3837.9mm representing 2000 and 2012 respectively with an erosivity index of 4695 to 19107.9 MJmmha⁻¹h⁻¹yr⁻¹. While the amount of rainfall for the coastal ranges region ranges from 3172.8mm to 4718mm with an erosivity index of 5129.88 to 8259.04 MJmmha⁻¹h⁻¹yr⁻¹. The result obtained from the study showed that rainfall within the study area is highly erosive in nature. This can be seen in the development of rills and enlargement of gully sites within the study area. Hence, this should serve as an input in soil erosion modeling for sustainable soil resource management.

Keyword: rainfall erosivity index, soil erosion, land degradation

1. INTRODUCTION

Soil erosion by water has been known to be a major environmental threat globally (FAO, 2019; Wang *et al.*, 2018; Aga *et al.*, 2018), degrading the soil and water resources thereby affecting agriculture and the environment (Schoonover and Crim, 2015; Adimassu, 2014). Soil erosion is caused simultaneously by rainfall, soil, vegetation, topography and anthropogenic factors (Orakwe *et al.*, 2021; Wischmeier and Smith, 1978). In developing countries, agriculture is the main stay of the economy. The improper use of land resources, population growth and climate change has put pressure on the



available land, hereby leading to decline in crop yield, environmental degradation and pollution.

In soil erosion study, empirical model such as; universal soil loss equation and revised universal soil loss equation has been used in modeling soil erosion globally. The considered input for the models are R , K , L , S , C and P (Orakwe *et al.*, 2021; Chadli, 2016; Gelagay and Minale, 2016; Fashae *et al.*, 2013). Rainfall-runoff relation is expressed as a function of R factor in the models. Soil loss is closely related to rainfall, partly through the detachment power of raindrops striking the ground and partly through the contribution of rainfall to runoff (Ekpo *et al.*, 2021; Giadrossich *et al.*, 2016; Merten *et al.*, 2015). Rainfall is the driving factor for erosion caused by water. It is considered as an important parameter, since the model is a detachment based concept (Wischmeier and Smith, 1978).

For water erosion to occur there must be rainfall erosivity and soil erodibility. The erosive force of rainfall is expressed as rainfall erosivity (Panagos *et al.*, 2015; Asadi *et al.*, 2008). Rainfall erosivity is the ability of the rainfall to cause detachment of soil particles while soil erodibility is the ability of the soil to resist detachment as a result of rainfall impact. Rainfall erosivity is climatic dependent, it cannot be controlled by humans but its impact can be reduced through the proper and adequate modification of other parameters that influence soil erosion such as; landcover, crop and land management factor. The rainfall-runoff erosivity factor R is generally known as one of the most important indicators of the erosive potentials of raindrop impacts (Lobo *et al.*, 2015).

The expanse of erosion caused by rainfall depends on the intensity, amount, duration and frequency of the rainfall, which are climate related (Ekpo *et al.*, 2021; Mondal *et al.*, 2016; Arun *et al.*, 2016; Panagos *et al.*, 2015). The factor R is the sum of erosive storm values EI_{30} occurring during a mean year, which is a function of the product of the total storm energy E multiply the maximum 30 minutes intensity (I_{30}) (Wischmeier and Smith, 1978) where E is in MJ/ha and I_{30} is in mm/hr. The detailed data for the determination of rainfall erosivity is a major setback in developing countries such as Nigeria. In soil conservation study, it is necessary to evaluate the rainfall within the study area for adequate soil and water resources management.

Attempts have been made by various researchers worldwide to establish correlations between the R factor calculated by the prescribed method and more readily available rainfall data, such as the daily and monthly rainfall (Henando and Romana, 2015; Leo and Heo, 2011; Bonilla and Vidal, 2011; Reinard and Freimund, 1994). In this case, one of the most used equations for R calculation is given by Arnoldus, (1980), which uses the average amount of precipitation for important number of years. The objective of this paper is to model the spatio-temporal variation of the rainfall erosivity R within Akwa Ibom State for soil erosion study using the rainfall average monthly data.

2. MATERIALS AND METHODS

Study Area

The location of the study is Akwa Ibom state, Nigeria and it is located within the trigonometric boundaries of 4°32' and 5°33' north latitude and 7°25' and 8°25' east longitude and a landmass of 7081km². The study area is generally a low-lying plain and riverine area with no portion exceeding 175m above mean sea level (Mendie and Akpan, 1999). The study area has upland and coastal region. The climate is divided into two seasons. The wet season last from April to October and the dry season last from November to March. The annual total rainfall ranges from 1875mm to 2500mm (Ogban and Obi, 2010) with a mean annual temperature that varies between 21°C and 29°C and a relative humidity of 60% and 85% (Ogban and Obi, 2010).

Data

The data used for this research is the rainfall climatic data. An average monthly rainfall data of 33 years (1985-2018) was obtained from the Nigerian Meteorological Agency (NIMET), Lagos, which represents the upland of the study area. While a rainfall data of 9 years (2010-2018) was obtained from the Akwa Ibom State Airport, Okobo, which represents the coastal region. This was done in order to show the spatial pattern of rainfall erosivity. Although a minimum of 20 years rainfall data is needed for rainfall erosivity study. The unavailability of data has limited the years used.

Methods

The method used in this study is based on average monthly and annual rainfall total to measure erosivity to calculate R -values as given by Arnoldus, (1980). It has been applied by (Tahiri *et al.*, 2016). It is an alternative procedure to estimate R in data scarce region. Table 1 shows the rainfall erosivity index of the class of the rainfall. The equation is given as;

$$R = 1.735 \times 10^{(1.5\log F - 0.8188)}$$

$$F = \sum_{i=1}^{12} \frac{P_i^2}{P}$$

R = Rainfall Erosivity $\text{MJmmha}^{-1}\text{h}^{-1}\text{yr}^{-1}$

F = Modified Fournier Index

P_i = Monthly rainfall (mm)

P = Total annual rainfall (mm)

Table 1: Classification of Rainfall Erosivity Index

Erosivity ($\text{MJmmha}^{-1}\text{hr}^{-1}$)	Erosivity Class
$R \leq 2452$	Low Erosivity
$2452 < R \leq 4905$	Medium Erosivity
$4905 < R \leq 7357$	Medium – Strong Erosivity
$7357 < R \leq 9810$	Strong Erosivity
< 9810	Very Strong Erosivity

Source: Carvalho (2008).

3. RESULTS AND DISCUSSION

Rainfall Runoff Erosivity Index

The result of the annual rainfall and the annual rainfall erosivity R for the upland and coastal zone of Akwa Ibom state are presented in table 2 and 3 respectively.

Table 2: Annual Rainfall P and Rainfall Erosivity Index R of Upland Zone of Akwa Ibom State, (1985-2018)

year	P (mm)	R	year	P (mm)	R
1985	2132.6	5720.1	2002	2341.4	7295.2
1986	1904.7	5775.4	2003	2095.2	6389
1987	2244.4	6560	2004	2221.6	6913.3
1988	2215	6663.8	2005	3026.9	10568.2
1989	2688.7	10484.5	2006	3373.7	12509.4
1990	2032.8	7280.4	2007	3396.8	14162.2
1991	2246.7	7734.4	2008	2970.6	10782.7
1992	2256.8	7827.5	2009	1944.1	4989.1
1993	2229.5	7805.5	2010	2762.1	12740.7
1994	2668.5	9075.8	2011	2880.3	11850.3
1995	2268.4	7085	2012	3837.9	19107.9
1996	2143.8	6866.1	2013	2941.3	9147.7
1997	1921.3	5625.3	2014	3027.2	10981.6
1998	2033.8	5084.1	2015	2967.4	9619
1999	2510.4	8217.5	2016	2477.9	7074
2000	1840.7	4695.1	2017	2643.6	8731.4
2001	2317.2	7369.4	2018	2317.9	7496.1

Table 2 represents the annual rainfall P and rainfall erosivity index R of the upland zone of Akwa Ibom State for the period of 34 years (1985-2018). The amount of rainfall for the region ranges from 1840.7 to 3837.9mm representing the year 2000 and 2012 respectively. This represents the highest and the lowest rainfall within the upland of the study area for the past 34 years. This shows that the rate and amount of rainfall within the study area is high. The rainfall erosivity index of the study area ranges from 4695 and 19107.9 $\text{MJmmha}^{-1}\text{h}^{-1}\text{yr}^{-1}$ as shown on Table 2. This represents the year 2000 and 2012 respectively. Figure 1 represents the graphical representation of the annual rainfall and rainfall erosivity of the study area. The graph shows that rainfall affects erosivity positively. It shows that the rainfall erosivity of the study area ranges from medium erosivity to very strong erosivity index. This is

as a result of the duration, intensity, amount, frequency and size of the raindrop. This signifies the occurrence of erosion within the study area as gullies have been recorded within the study area Udoumoh *et al.*, (2018).

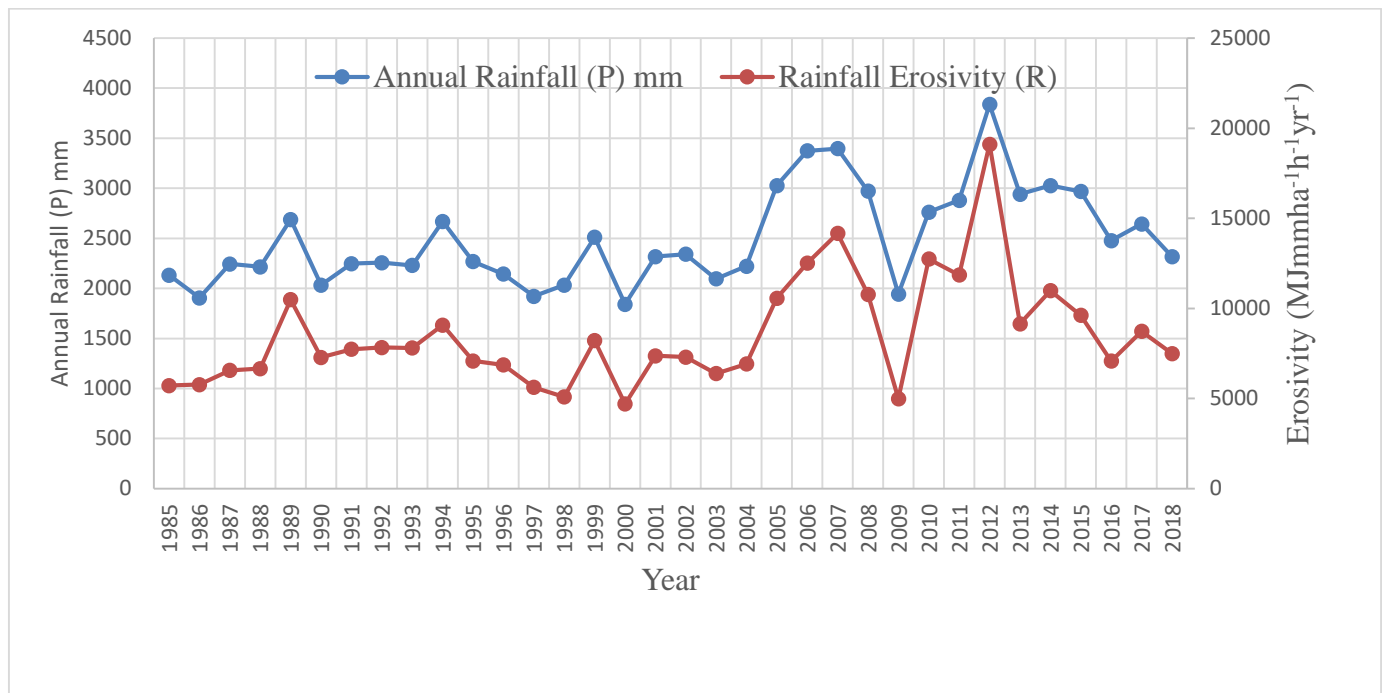


Figure 1: Temporal Variation of Annual Rainfall and Erosivity of Upland Zone of Akwa Ibom (1985-2018)

Table 3: Annual Rainfall *P* and Rainfall Erosivity Index *R* of Coastal Zone of Akwa Ibom State, (2010-2018)

year	<i>P</i> (mm)	<i>R</i>
2010	3172.8	7432.08
2011	3968.8	7998.73
2012	4718.3	8259.04
2013	4306.5	5129.88
2014	4214.9	7231.49
2015	4050.6	7391.88
2016	3616.5	6836.86
2017	4082.9	6785.71
2018	38669.7	7556.2

Table 3 represents the annual rainfall *P* and rainfall erosivity index *R* of coastal zone of Akwa Ibom state for 9 years (2010-2018). The range of rainfall is giving as 3172.8mm to 4718.3mm, which represents the amount of rainfall across the coastal zone of the study area. The high amount of rainfall can be attributed to the nearness to the Atlantic Ocean. This signifies that the rainfall erosivity within the coastal zone of the study area is highly erosive. The rainfall erosivity index of the coastal zone ranges from 5129.88 to 8259.04 MJmmha⁻¹h⁻¹yr⁻¹, which shows an erosivity of medium-strong erosivity to strong erosivity indices over the coastal region of the study area. Figure 2 shows a graphical representation of the annual rainfall data and the erosivity of the study area. This shows a high rainfall amount and a corresponding erosivity of very high erosive indices.

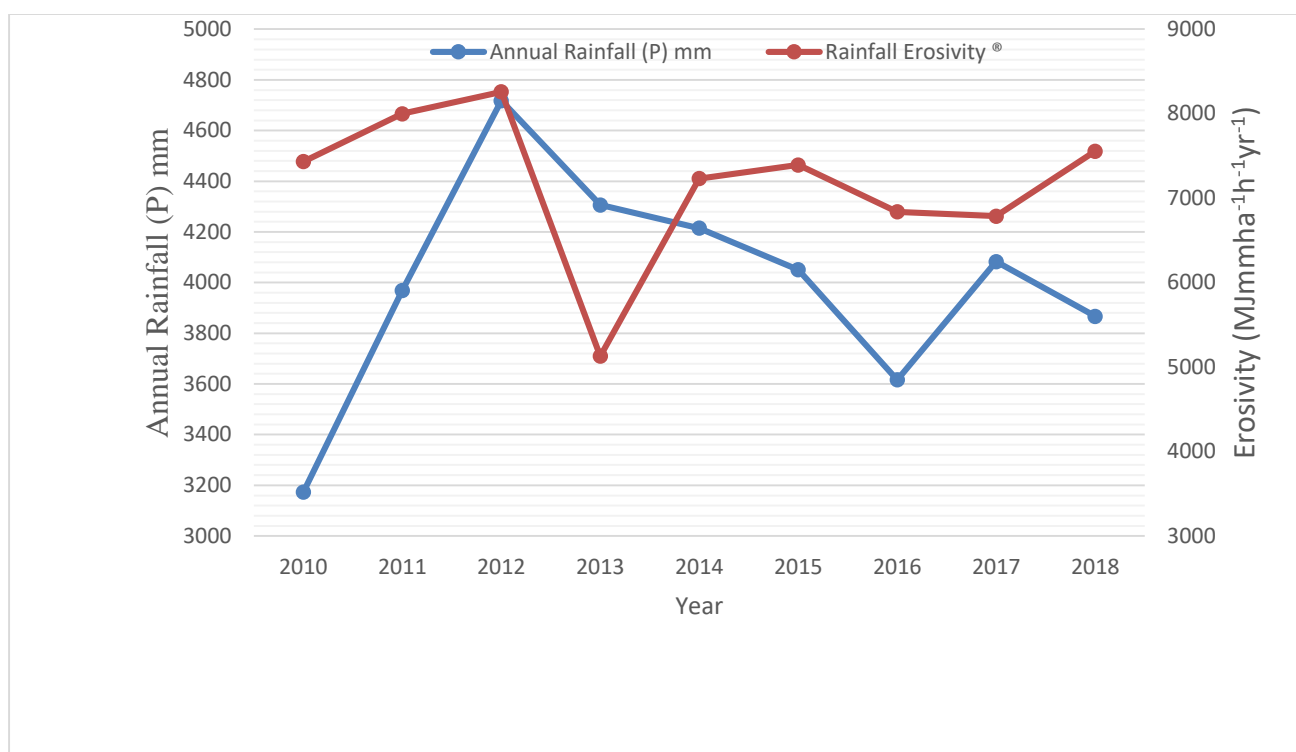


Figure 2: Temporal Variation of Annual Rainfall and Erosivity of Coastal Zone of Akwa Ibom (2010-2018)

From the results obtained, it shows that the erosivity index of the study is very strong at the upland and strong at the coastal zone according to the rainfall erosivity index classification. Similar work has been done by Comman *et al.*, (2019) in Spain. Andoh *et al.*, (2012) carried out similar research in the tropics of Ghana and observed that an increase in rainfall will lead to an increase in the rainfall erosivity index. Ezemonye and Emeribe, (2012) in their study observed that the rainfall at the coastal zone is highly erosive, which conforms to the findings of this research.

4. CONCLUSION

In soil management, the first step is to understand the rainfall climatic factor that affects soil loss and degradation. Rainfall erosivity is an important parameter in soil erosion modeling since it initiates soil detachment and transportation through runoffs. From the study it is seen that rainfall affects erosivity as shown on the graphs displayed. The rainfall erosivity index obtained shows that the rainfall energy of the study area is very strong erosivity as described by Carvalho (2008). It therefore signifies that rainfall is the driving force in initiating soil erosion within the study area. Hence, the need to adapt adequate crop and land management practices that will slow down the processes of soil erosion within the study area.

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Conflict of Interest

The author declares that there are no conflicts of interests.

Data and materials availability

All data associated with this study are present in the paper.

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